In search of light therapy to optimize the internal clock, performance and sleep

Geerdink, Moniek

Chapter 4

Is it possible to fight an energy dip at the office with blue light?

Moniek Geerdink[1], Jeri Nijland[1], Domien G.M. Beersma[1], Vanja Hommes[2], Marijke C.M. Gordijn[1,3], Emma J. Wams[1]

[1]Department of Chronobiology, GELifes, University of Groningen, The Netherlands; [2]Philips Consumer Lifestyle, Drachten, The Netherlands; [3]Chrono@Work B.V., Groningen, The Netherlands

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Abstract

Light has non-image forming effects on alertness and performance in humans. In offices light levels might be too low to elicit these effects. Extra artificial light may therefore improve alertness and performance of employers in a working environment. In the present study the question was whether 3 hours of extra blue light affected alertness and performance, given in accordance to the timing of a daily energy dip that subjects reported to experience. The study applied a counter-balanced 1-day experimental and 1-day control cross-over design in an office environment in 44 participants. On the control day participants were exposed to their regular office lighting; on the experimental day, 3 hours of extra blue light were added to the regular office light. Blue light was provided by a blue LED-lightstrip (280x25 mm2; peak transmission 480 nm; prototype Philips, Drachten, The Netherlands) which was placed on top of the computer monitor. In individuals suffering from an afternoon dip, extra blue light prevented the usual decrease in cognitive performance, seen in fewer errors ($F_{1,12}=5.7$, $P<0.05$). Furthermore, it was found that early types performed different from late types under light exposure at different times of the day. This study demonstrates that in an office environment relatively low intensity blue light can have effects on cognitive performance and that the timing of light exposure (when given during the individual's usual energy dip period) can influence these effects. Knowledge about the use of individualized lighting is useful to optimize the implementation of light devices in the work environment.

Introduction

Humans are a diurnal species, spending most of their waking time in the light phase of the day. Many aspects of our behaviour also depend on light in our environment. The fact that light is necessary for vision is evident; however there are also several non-image forming (NIF) effects of light. Examples of NIF effects include circadian entrainment, hormone regulation (reviewed in Shanahan & Czeisler 2000), pupillary constriction, body temperature and heart rate (Scheer et al. 2004, Cajochen et al. 2005) and maybe even modulation of sleep intensity (Hubbard et al. 2013, Wams et al. submitted, Geerdink et al. submitted). Light has also been found to modulate alertness and cognitive performance (reviewed in Cajochen 2007; Chellappa et al. 2011). Despite of all these known NIF effects of light, there are no studies that compare the effects of light on alertness and performance during different moments of a working day in a field study. This will be examined in the present study.

Earlier studies found that NIF effects are mediated by a third type of photoreceptor in the ganglion cell layer of the retina, known as photosensitive retinal ganglion cells (pRGCs) (Berson et al. 2002, Hattar et al. 2002). The functional photopigment of the pRGCs is melanopsin, an opsin-like protein with a peak spectral sensitivity around 480 nm, which is in the blue part of the spectrum (Thapan et al. 2001, Berson et al. 2002, Panda et al., 2005). Besides the direct light input to the pRGCs, the cells receive integrate light information collected by rods and cones (review Hatori and Panda, 2010). The pRGC's project to several non-image forming related areas of the brain, including the suprachiasmatic nucleus (SCN) of the hypothalamus which is considered the principal circadian pacemaker. Other areas are for instance the ventrolateral preoptic nucleus (VLPO), the intergeniculate leaflet (IGL), and the olivary pretectal nucleus (OPN), which are involved in regulation of sleep-wake states, attention, and arousal (Gooley et al. 2003, Morin and Blanchard 2005, Hattar et al. 2006, Szkudlarek et al. 2012).

Most research into the alerting and performance improving effects of light have been conducted during the late evening and early morning hours (Lockley et al. 2006, Rüger et al. 2006, Cajochen 2007, Phipps-Nelson et al. 2009, Chellappa et al. 2011). During the night, the largest effects of light on alertness and performance are expected, because in humans there is a large decline in alertness and performance as the night proceeds and therefore at this time there is the largest improvement possible (Cajochen et al. 1999).

While the knowledge obtained by studying the effects of light on performance during the night is interesting by itself, extra light may be beneficial for dayworkers as well. The daily light intensity in offices is often low and low light levels are related to poor well-being, health and sleep problems (reviewed in van Bommel et al. 2006, Harb et al. 2014). The Dutch lighting norm (www.nsvv.nl, NEN EN 12464-1:2003) includes no criteria for vertical illuminance in the office environment, but requires that the horizontal light intensity for writing and reading should be 500 lux on the working plane. The result is that the vertical illuminance is often only around 250 lux (reviewed in Górnicka, 2008). It seems unlikely that this amount of light exposure is sufficient to improve performance and alertness during daytime, because even during night-time it would elicit only limited to medium effects (Cajochen et al. 2000, Hébert et al. 2002, Hommes & Giménez 2015). Extra light in the office environment may therefore be a way to enhance alertness, performance and well-being of office day workers. A few lab studies conducted during daytime showed that bright light is able to improve alertness and performance compared to dim light conditions in a controlled environment (Bersani et al. 2008, Phipps-Nelson et al. 2003, Rüger et al. 2006). That daytime light is also able to enhance the physiology of performance is supported by an fMRI-study of Vandewalle and colleagues (2006). Exposure to 21 minutes of bright light (>7000 lux) resulted not only in reduced subjective sleepiness scores, but also in enhanced thalamic activity, which indicated that it modulated cortical responses. These brain areas have been implicated in attention and alertness regulation, which supports the notion that light modulates NIF cognitive processes.

Thus, in a controlled environment it is demonstrated that also during daytime high light intensities are able to reduce sleepiness and improve performance. However, in these studies participants were often sleep and/or light deprived prior to measurements (Phipps-Nelson et al. 2003, Rüger et al. 2006, Vandewalle et al. 2006). This is still quite different from a working environment, wherein people are already exposed to a certain amount of office light and are often not seriously sleep deprived.

In the study of Smolders and colleagues (2012) the researchers assessed the light effects in a semi-natural office setting. In that study they looked at the vitalizing effects of 200 lux versus 1000 lux in the morning or the afternoon on both subjective alertness and cognitive performance during the day. The results showed that higher intensity light in the morning as well as in the afternoon reduced sleepiness and improved cognitive performance. Moreover, the cognitive performance effects were more pronounced in the morning condition and near the end of the exposure period. Two other field studies (Mills et al. 2007, Viola et al. 2008) assessed the effects of blue-enriched white light (17000K) compared to standard white light (2700K and 4000K respectively) during daytime on various parameters in retrospect. Over longer periods of time they applied questionnaires that included questions concerning sleep, sleepiness and performance. Both studies found that under blue-enriched light exposure, participants scored higher on all performance parameters compared to the standard white light (4000K) condition. Although these studies suggest alerting and performance enhancing properties of extra (blue) light, there is not much known about optimal timing of light in relation to NIF effects during daytime. Furthermore, it may well be that the optimal timing varies between individuals since there is inter-individual variation in energy patterns over the day, which is probably related to individual differences in internal time as reflected in ‘chronotype’ (Carrier and Monk 2000, Roenneberg et al. 2003). The individual variation in performance and sleepiness levels over the day is probably a consequence of the interaction of the differences in an individual’s biological clock and differences in build-up of sleep pressure (reviewed in Blatter and Cajochen 2007). Up till now there are no light intervention studies that have taken this individual variation into account.

In summary, previous studies suggest that extra light during the day is an effective and relatively easy way to improve alertness and performance, and thereby improve productivity, of office employees. However the individualized optimal timing of extra light during the day has to be identified. Many subjects are capable of indicating a time of day in which they are likely to suffer from a subjective 'energy dip', at which they experience a dip in performance. In this study, individuals will be exposed to extra light at the time of their daily energy dip. Therefore, the aim of this field study was whether relatively low intensity blue light timed around one's subjective energy dip, either during the morning, noon or afternoon, had effects on alertness and performance during the workday. In addition, we examined retrospectively the possible interaction with different chronotypes. It was hypothesized that in this field study, extra blue light would have acute effects on improving sleepiness and cognitive performance. Effects can be expected to be larger during periods of lowest energy. As a consequence, late chronotypes would be expected to benefit from morning light, whereas early types would be expected to benefit from afternoon light.

Material and Methods

Participants

Fourty-four healthy participants (m/f, 19/25) were recruited. Subject characteristics are summarized in table 1. Participants had to have computer-work for at least 3 hours a day, for at least one day a week and had to be available on the same weekday for two weeks. Furthermore, participants had to experience a subjective dip in energy either in the morning, around lunch or late afternoon, which was characterized by experiencing lower performance and an increase in sleepiness compared to the rest of their working day.

Potential participants completed a general health questionnaire, the Pittsburgh Sleep Quality Index (PSQI) (Buysse et al. 1989), the Beck Depression Inventory (BDI-II) (Arnau et al. 2001), and the Munich Chronotype Questionnaire (MCTQ, Roenneberg et al. 2003). The MCTQ was used to assess chronotype by calculating mid-sleep time on free days, irrespective whether they used an alarm clock or not, corrected for accumulated sleep debt on workdays (MSFsc, Roenneberg et al. 2004). The energy dip groups differed from each other with respect to chronotype; participants with a morning dip or a noon dip had a significantly later MSFsc, compared to participants with an afternoon dip (Morning group: MSFsc= 4.9 ± 1.1, Noon group= MSFsc 4.7 ± 1.1, Afternoon group: MSFsc= 3.8 ± 1.1, $F_{2,38}$= 3.63, $P<0.05$). Individuals with low sleep quality (PSQI > 10) or with a moderate to severe depression score (BDI-II > 14) were excluded. All participants confirmed to be free of eye disease or psychiatric illness and were not on current sleep or photosensitizing medication. Other exclusion criteria were travelling over two or more time zones in one month prior to the experiment and having shift work in three months prior to the experiment. All participants proved to have normal colour vision (Ishahara test) and reported only moderate caffeine (limit at ≤ 8 cups/day, group average 2.9 ± 2.5 cups/day) and alcohol (limit at ≤ 10 units/week, yes or no question) intake. Since this study has no medical research questions, nor did it use a medical device, according to Dutch law no approval of a Medical Ethics Committee was necessary. The researchers took care that all data were collected according to the institutional rules and regulations of research involving humans and data were stored in agreement with the Dutch Personal Data Protection Act ('Wet bescherming persoonsgegevens', Wbp; 2000). Participants provided written informed consent and were compensated for their participation.

Table 1 - Participant characteristics

	N	Mean	SD	Range
Age (total)		34.7	8.27	22-55
Morning light group	13	31.5	7.96	22-47
Noon light group	14	33.7	9.60	25-55
Afternoon light group	17	38.0	6.40	28-47
PSQI (total)		4.59	2.35	1-10
Morning light group	13	4.38	2.40	1-9
Noon light group	14	4.57	2.59	1-10
Afternoon light group	17	4.76	2.22	2-10
BDI (total)		4.30	4.54	0-14
Morning light group	13	4.77	4.69	0-14
Noon light group	14	3.50	4.36	0-12
Afternoon light group	17	4.59	4.77	0-14
MSFsc (total)		4.47	1.16	2.48-7.51
Morning light group	13	4.99	1.09	3.58-6.87
Noon light group	14	4.63	1.09	3.78-7.51
Afternoon light group	17	3.85	1.10	2.48-6.57

Blue light intervention

All participants were tested in 2 conditions; a control condition in which they were exposed to their regular office lighting, and a blue light condition in which they were exposed to their regular office light and on top of that to three hours of extra blue light timed to coincide with their individual energy dip. This extra blue light was provided by a blue LED-lightstrip (280x25 mm2; Philips, Drachten, The Netherlands) which was placed on top of the computer monitor. The light had an intensity of 45 lux, 500 mlux at the level of the eye at a distance of 60 cm and a peak wavelength of 480 nm. At this distance the number of blue photons that was received was 7e17 m-2 s 1, which has been found to be effective in improving performance in the study of Viola et al. (2008) and decreasing sleepiness according to the dose response curve published by Hommes and Giménez (2015). The light emitted by the blue-LED lightstrip on top of the computer screen was tested by Philips in 76 individuals for usage comfort. No eye complaints were reported. The device was classified as exempt from risk according to Photobiological Safety Standard IEC 62471:2006. No eye complaints were reported. The spectral composition at eye level was measured with and without the lightstrip on a spectrophotometer (Jeti' specbos 1211UV, Sensor = 90degrees Diffusor, spectral sensitivity 1 nm: 380-780). Figure 1 shows the spectral composition of the control office light conditions and of the extra blue light conditions. The experimental condition contained a much higher intensity in the blue-light area. Participants received instructions regarding the timing of the light. The timing was defined according to the experimental protocol (see next paragraph). At the scheduled time, the light was turned on by the participant, after which it turned off automatically after 3 hours. Participants were asked to sit in front of the light as much as possible, however they could leave for short intervals (not more than 5 minutes per hour) for instance for a toilet visit.

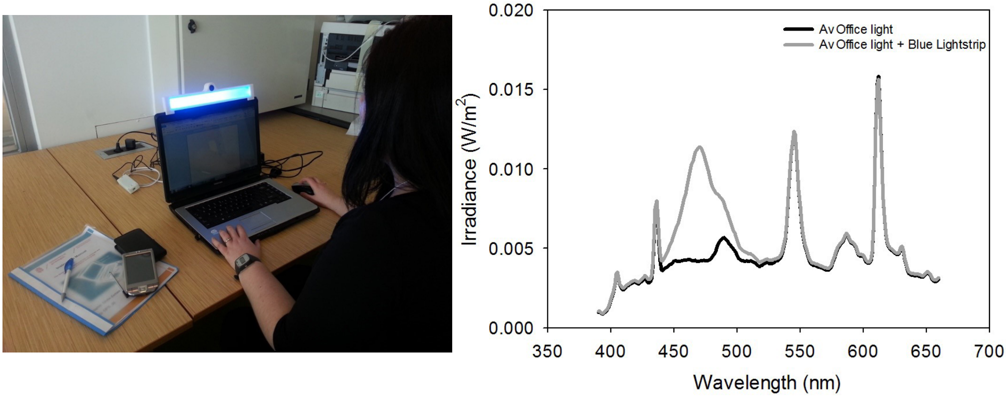

Figure 1. A: Photograph of the setup of the study at the office with the blue light strip mounted on the laptop monitor B: The light spectra based on the lighting in the offices that were included in the present study. To two lines represent the spectrum with the blue lightstrip switched on (grey line) or the spectrum with the blue lightstrip switched off (black line).

Experimental Protocol

The study was performed in winter between January and February 2013, in the Groningen Area, The Netherlands. A 1-day experimental and 1-day control cross-over design was used, in a counterbalanced order. The two days (between Tuesday and Friday) had to be on the same day of the week for each subject. Not more than 2 weeks in between the conditions was allowed. Before the start of the experiment, participants plotted their general energy pattern as a function of the time of their working day. Lowered energy was indicated by a lowering of the line in this graph. Based on their point of lowest energy, participants were assigned to receive 3 hours extra blue light either in the morning, noon, or afternoon. For a schematic overview see figure 2 and see table 1 for the subject characteristics of the 3 groups.

The blue light exposure was checked for compliance by means of a small light sensor (HOBO, Mulder-Hardenberg group, Haarlem, The Netherlands) worn as a necklace from waking up until going to bed on the testing days.

Both testing days were identical with regard to the timing and type of measurements. Measurements consisted of the Karolinska Sleepiness scale (KSS) (Akerstedt and Gillberg, 1990) and of cognitive performance tests (see next paragraph), all performed on a Personal Digital Assistant (PDA) device. Timing of the measurements was adapted individually to timing of the light, see figure 2. In addition, after waking up on the measurement days and on the mornings after the measurement days, participants completed a diary which included questions about their sleep, caffeine consumption and their energy profile of the previous day. Caffeine consumption was a question in the diary, because caffeine has an effect on alertness and performance (Barry et al. 2005), especially in combination with extra light exposure (Wright et al. 1997).

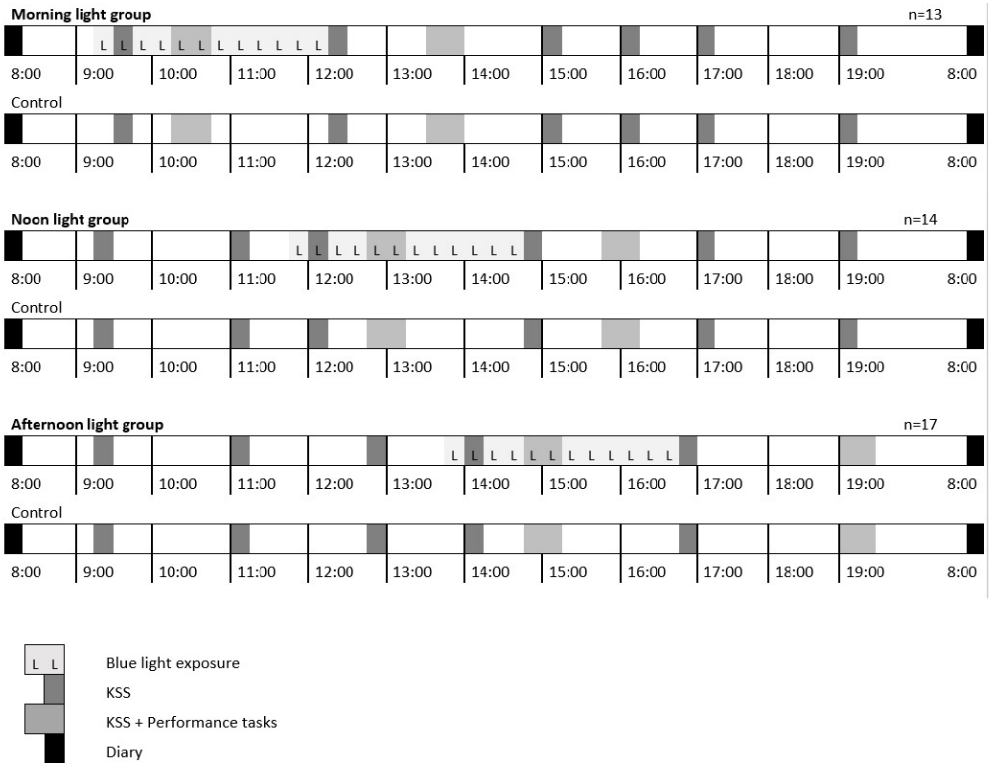

Figure 2. The average protocol time scheme for the three different groups. The timing of blue light exposure was individually adapted to energy dip and to working hours, and therefore different between individuals. The timing of the performance tasks was based on the individual timing of light and therefore also different between individuals. Each individual within a group completed the experimental day as well as the control day. The planning of tasks was the same on both the experimental day and the control day. The only difference between the two days was the blue light exposure period, indicated by the bars with 'L', on the experimental day.

<u>Cognitive performance tasks</u>

At 2 (morning light group) or 3 (noon and afternoon light group) specific times during the day (figure 2) participants completed a test block on a handheld minicomputer (PDA, HP Ipaq114) that consisted of four cognitive performance tasks in combination with the KSS sleepiness questionnaire. The test blocks were scheduled either during and after light exposure (morning light group) or before, during and after light exposure (noon and afternoon group light group). The timing of the test blocks with respect to light exposure were the same in every condition, see figure 2. This means that the 'before' test block was 1 hour before the start of the light, the 'during' test block was after 1 hour of turning on the light, and the 'after' test block was after 1 hour of turning off the light, except for the afternoon group (the last test block was performed after diner at home).

The performance tasks included a Psychomotor Vigilance Task (PVT), a counting Stroop task, a Sustained Attention to Response Task (SART) and a 2-back test. Reaction time and number of errors were output variables in all tests.

The PVT is a sustained attention test (Lamond et al. 2008). In each trial, participants were presented a 0 on the screen. As soon as the numbers started to increase, a button had to be pressed as quickly as possible. The interval between trials varied between 500 and 9000 ms in order to minimize anticipatory behaviour. The number of trials per test block was variable, with a mean of 35.4 trials (sd 3.00). The task lasted 3 minutes (Loh et al. 2004).

The colour Stroop test is often used to measure selective attention and interference sensitivity (MacLeod, 1991). In this counting Stroop, participants were shown sets of 1-4 identical words and had to select the number of words on the screen, regardless of the meaning of the word. This counting Stroop test was chosen, in contrast to a colour Stroop test, because environmental light differed in colour between conditions and this might have influenced the perception of colour of the words. Stimuli in the counting Stroop test were divided into two blocks. The test started with a 'neutral' stimuli block, which consisted of animal name words. This block was followed by an 'interference' block, where number words 'one' until 'four' were written. Upon the presentation of two times the word 'one', the subject needs to respond with 2, etcetera. The combination of the neutral and interference block was repeated 3 times, making for a total of 96 trials. The stimuli were presented for 1000 ms, with 1000 ms intervals. In total the Stroop lasted for 3 minutes.

The SART measures response control (Robertson et al. 1997). It is similar to a Go/NoGo task, which requires participants to monitor single digits presented rapidly on screen, and respond to each one that appears (called a Go target, in the present study to the numbers 1,2,4,5,6,7,8,9), except for a particular pre-defined digit (called NoGo target, in the present study the number 3). Trials were separated by a fixation cross presented for 900 ms, followed by the stimulus, which was shown for 250 ms. The SART consisted of 225 trials and lasted for approximately 5 minutes.

The 2-back task is used as a measure of working-memory (Owen et al. 2005). It is a task in which stimuli (in this case numbers) are presented individually on a computer screen, and the participant must indicate if the current stimulus and the nth-stimulus (n=2) prior to the present stimulus match. The higher the n, the stronger are the demands of executive functioning. The task was comprised of 81 trials, with each stimulus shown for 3000 ms and an inter-stimulus interval of 500 ms. The duration of the test was 3 minutes.

Data handling

Since participants were in their regular working environment, with their general working activities, some tests were not completed at the scheduled times. Participants were excluded entirely from a particular analysis if they did not contribute to all test blocks. An exception was made for the sleepiness data, in which singular missing values were estimated by averaging the values before and after the missing value. We applied this 6 times in 6 different individuals. For each of the parameters the maximum number of participants was used for analyses. Commission and omission errors were removed from the list of reaction time values. Errors of commission arise when participants respond before the stimulus is given. Errors of omission are those wherein the participants fails to respond to a stimulus or respond with an unusually long reaction time which falls outside the normal distribution of reaction times for the study population. To check for unusually long or short reaction times the distribution of the raw data was plotted, after which outliers could be observed and thresholds were set to a maximum of 5% of the data points. Depending on the distribution of values, these cut-off criteria could be less than 5%. This resulted in the removal of 0.15 % and 5.0% outliers on each side of the N-back distribution; 0.5% and 4.0% outliers on each side of the PVT distribution; 5.0% outliers on each side of the SART distribution and 0.1% and 0.5% outliers on each side of the STROOP distribution. Resulting cut off criteria for reaction times per task: PVT <251 ms & >549 ms, STROOP <400 ms & >988 ms, SART <132 ms & >516 ms, N-back <298 ms & >1381 ms. Additionally, MSFsc scores were plotted as a frequency distribution, to see whether the MSFsc scores were normally distributed. Statistical analysis showed a normal distribution (P>0.05) on the Shapiro-Wilk test. To obtain an overall picture of performance, a composite performance index (CPI) was calculated by combining the data of all four performance tests. Both the mean RTs and the percentages of errors of these tests were normalized separately for each test by dividing individual values by the average value of all subjects, after which the resulting values of all tests were averaged per subject. The result was a CPI for mean RT, a CPI for percentage of errors and an overall CPI that contains data of both the mean RT and the percentage of errors. A higher value means worse performance (higher number of errors and longer reaction time).

Statistics

SPSS was used for all statistics (Version 15.0, SPSS Inc., Chicago, Illinois, USA). The effects of extra blue light for 3 hours were tested for subjective sleepiness, caffeine consumption, and for composite performance indices of the cognitive performance tasks (CPI RT, CPI percentage of errors, and overall CPI). Repeated measures ANOVA tests were used to test for the within-participants main effects of light (control vs. extra blue light) and interaction effects of light and time (before light, during light, after light) for each energy-dip time group (morning group, noon group, afternoon group) for all parameters. In case of a condition X time effect, contrasts were used, since it was hypothesized that turning on and off the light might have different effects.

In addition a repeated measures ANOVA was performed on all data during light exposure, with energy-dip group and chronotype as between factors and light condition as the within factor to examine if different chronotypes performed differently during different energy dip moments under light exposure. To include chronotype as a between factor, participants were divided into chronotype categories according to their MSFsc (early N= 16, intermediate N= 10, late N= 15). Three participants did not provide us their MCTQ and were classified as chronotype ‘unidentified’. The division was based on the Dutch chronotype database (n=8074, Gordijn, pers. communication) and was matched for age and gender. Since caffeine consumption was found to be significantly different between the control condition and the light condition for the noon group (section ‘caffeine consumption’ of the results), and caffeine consumption can influence alertness (ref), this variable was included as a covariate in each test.

Results

Caffeine consumption

In the noon group, less caffeine was consumed on the day with extra blue light compared to the control day, on average 2.5 (±0.5) and 3.4 (±0.7) cups respectively, $F_{1,13}=6.8$, $p<0.05$). For the other groups, there were no significant differences found for caffeine intake between the control and energy-dip timed light conditions (morning $F_{1,11}=0.80$, $p=0.39$, afternoon $F_{1,11}=0.66$, $p=0.43$). Still, because caffeine intake has an influence on alertness within individuals, the difference in caffeine intake between the control and light day was included as a covariate in all subsequent analyses.

Sleepiness scores (KSS) over the day

The time course of subjective sleepiness, measured with the Karolinska Sleepiness Scale (KSS), for the three different groups is depicted in figure 3A. For the morning energy dip group it was only possible to evaluate the effect of the blue light on sleepiness during and after light exposure since light exposure started immediately after arriving at the office. For the noon and afternoon energy dip groups it was also possible to assess the effect of turning on the light. To discriminate the acute effects of turning on and off the blue light from the effects during the rest of the day, the time points before, during and after light exposure were also separately included in the tests. For the morning energy dip group, the two time points during light exposure on average at 9:37am (± 32 min.) and at 11:00 am (± 62 min.)) and the time point directly after light exposure on average at 12:42 pm (± 40 min.) were included. For blue light in the morning there was no significant main effect of condition for mean reaction time ($F_{1,11}=0.01$, $P=0.95$), yet a trend for the interaction effect between condition and time ($F_{2,10}=4.0$, $P=0.09$) was found. This means that the extra blue light tended to induce a larger decline in sleepiness, see Figure 3A left panel.

For the noon light group sleepiness scores shortly before light exposure on average at 10:54 am (± 48 min.), during light exposure on average at 12:55 pm (± 41 min.) and at 2:00 pm (± 45 min) and after light offset on average at 3:45 pm (± 29 min.) showed neither a significant main effect for condition ($F_{1,12}=2.0$, $P=0.18$), nor interaction effect between condition and time ($F_{3,10}=0.4$, $P=0.79$), see figure 3A middle panel.

For the afternoon energy dip group sleepiness scores shortly before light exposure on average at 12:54 pm (± 35 min.), during light exposure on average at 2:17 pm (± 42 min.) and at 3:59 pm (± 36 min.) and after light offset on average at 5:02 pm (± 38 min.), showed a trend for a main effect for condition ($F_{1,14}=3.34$, $P=0.09$). Before the light was turned on, sleepiness seemed already to be attenuated in the light condition compared to the control condition, see Figure 3A. No interaction effect between condition and time ($F_{3,12}=0.6$, $P=0.63$) was found, see figure 3A right panel.

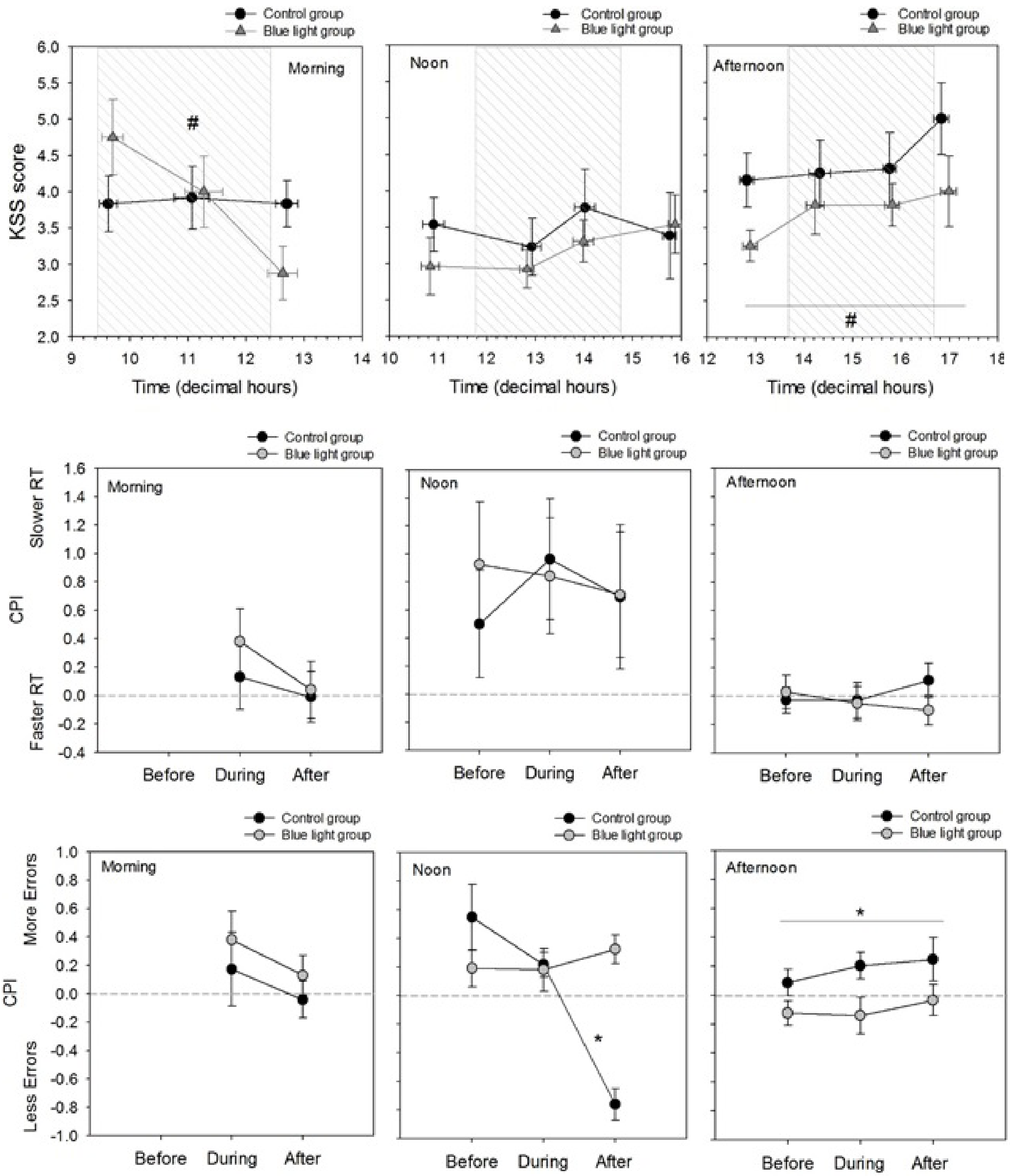

Figure 3. A: The average KSS patterns around light exposure for the group that received either blue light exposure in the morning (left, Time X Condition interaction; #P<0.1), blue light exposure around noon (middle), or blue light exposure during the afternoon (right, Condition; #P<0.1). The striped grey

box represents the average blue light exposure period on the experimental day. Because the timing of the blue light (and tasks) was individually adapted to energy dip and working hours, the timing of completing the KSS was different between individuals. The vertical error bars represent the S.E. of the KSS scores. The horizontal error bars represents the S.E. of the timing of completing the KSS scores.
B: The average composite performance scores (CPI) of reaction time (RT ± S.E.) for the group that received either blue light exposure in the morning (left), blue light exposure around noon (middle), or blue light exposure during the afternoon (right). For the group that received morning light, there were no performance measurements before the light was switched on.
C: The average composite performance scores (CPI) of number of errors (± S.E.) for the group that received either blue light exposure in the morning (left), blue light exposure around noon (middle, Time X Condition interaction; *$P<0.05$), or blue light exposure during the afternoon (right, Condition; *$P<0.05$). For the group that received morning light, there were no performance measurements before the light was switched on.

Performance CPI scores

The composite performance indexes (CPI), composed of the SART, N-back, PVT and STROOP tasks of the energy dip groups are depicted in figure 3B and 3C. The CPI of the reaction times (RT) shortly before, during and after blue light exposure are represented in Figure 3B and the CPI of the number of errors in Figure 3C. For the morning energy dip group it was only possible to evaluate the effect of the blue light on the CPI scores during and after light exposure. With respect to RT no significant effects were found for condition in none of the groups (morning: $F_{1,8}=0.8$, $P=0.41$, noon: $F_{1,10}=0.15$, $P=0.71$, afternoon: $F_{1,12}=0.0$, $P=0.96$). Also no interaction effect for condition X time with respect to RT were found (morning: $F_{1,8}=1.3$, $P=0.29$, noon: $F_{2,9}=0.7$, $P=0.52$, afternoon: $F_{2,11}=0.8$, $P=0.47$). With respect to the CPI of the errors in the morning group neither significant differences were found for condition ($F_{1,8}=0.1$, $P=0.71$) nor significant differences were found for the condition X time interaction ($F_{1,8}=0.1$, $P=0.74$,). In the noon group no significant difference was found for condition ($F1.10=0.7$, $P=0.52$), yet a significant difference was found for the condition X time interaction ($F_{2,9}=6.6$, $P<0.05$), see Figure 3C, middle graph. In the afternoon group there was a significant difference for condition ($F_{1,12}=5.7$, $P<0.05$), though not for the condition X time interaction ($F_{2,11}=0.2$, $P=0.82$), meaning that participants in the afternoon energy dip group had overall less errors in the blue light condition, even though they already started with less errors before the light turned on, see Figure 3C, right graph.

To test if chronotypes performed differently under blue light exposure in different energy dip groups, all the data of the CPI RT and CPI error scores were tested. In this case, energy dip group and chronotype were included as between factors and light condition was included as a within factor. For the CPI RT scores no significant differences were found (Condition: $F_{1,29}=0.0$, $P=0.95$, Condition X Energy dip group X Chronotype: $F_{4,29}=0.9$, $P=0.49$). However, for the CPI errors a significant difference was found for condition (Condition: $F_{1,29}=4.9$, <0.05) as well as for the interaction effect Condition X Energy dip group X Chronotype (Condition X Energy dip group X Chronotype: $F_{4,29}=3.0$, $P<0.05$), see also Figure 4. Early types performed worse during light in the morning while better during light around noon and slightly better in the afternoon. Late types showed no effect of light on performance in the morning and afternoon, but performed better at noon.

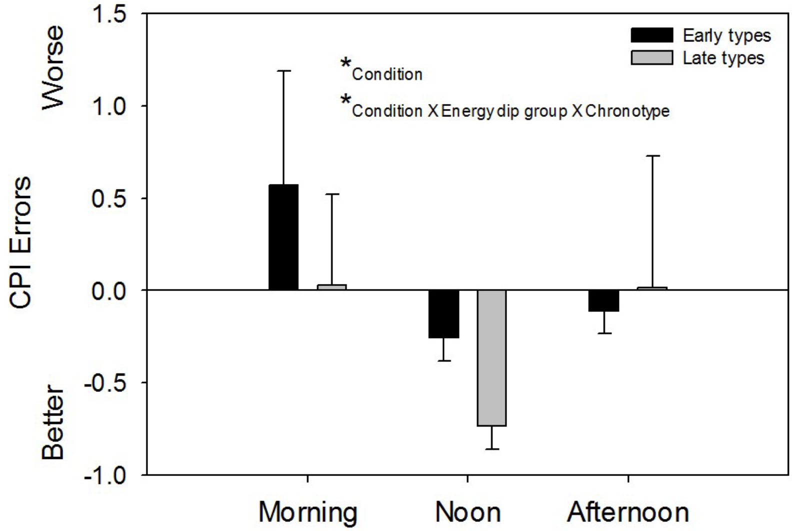

Figure 4. The overall composite performance scores (CPI) of the number of errors (± S.E.) for all the energy dip groups (morning, noon, afternoon) deviated for early chronotypes 'early' and late chronotypes 'late' during blue light exposure (Condition; *P<0.05, Condition X Energy dip group X Chronotype interaction; *P<0.05).

Discussion

The present study investigated the acute effects of extra blue light on alertness and performance during the working hours especially to overcome an interval with relatively low subjective energy. Therefore the extra light was presented during the intervals that subjects indicated to experience an energy dip. Furthermore, it was examined whether these effects were different for different chronotypes.

The present data showed that especially people suffering from an afternoon dip seem to benefit from extra blue light during this time of the day. In the control condition participants performed worse in the sense that they made more errors during the afternoon. In addition there was a trend that the increase in sleepiness was attenuated as well. Our observations are consistent with the fact that the afternoon is the most common time of increased sleepiness in people and at this time sleep latency is at its shortest during daytime (reviewed in Monk, 2005). Bes et al. (2009) proposed that the afternoon dip is the resultant of a secondary increase in need for sleep between the homeostatic build-up of sleep need and a drop in the circadian drive for wakefulness. This would suggest that the largest improvement to counteract this increased perception of sleep need could be realized during the afternoon, and this is consistent with the findings in the present study.

For those who received light at noon due to a perceived energy dip at this time, the NIF effects were not that clear. Performance, indicated by the number of errors, relatively improved in the control condition at the time when light was switched off in the light condition. No other effects of light on performance at this time of day were found. Also no effect of blue light on subjective sleepiness was found. However, the noon energy dip group was the only group in which there was a significant decrease in caffeine consumption during the day of the light condition. Similar to light, caffeine has been shown to be effective in enhancing alertness and cognitive performance (reviewed in Glade, 2010) and the effects are even similar in the brain (Barry et al 2005). It is only possible to speculate about the cause of the reduction in caffeine consumption in this group. It would be interesting if this decrease is a result of subjects feeling they do not need the caffeine since they experience the alerting effects of the light. However, one of the other causes may be that these subjects normally consumed the most caffeinated drinks during lunchtime and that they skip these during the light condition, as they were asked to remain at their desk as much as possible during the period of light exposure. Still, in the blue light condition the participants did not show an increase in their sleepiness scores, despite less caffeine intake. A prospective study is needed to test whether the use of extra light during working hours changes the amount of caffeine consumption.

The participants that experienced reduced energy in the morning and were exposed to extra light at that time of day did not seem to benefit objectively from the light in the morning, even though they felt less sleepy after use of the blue light. This finding was in contrast to expectations, as it was expected that especially late types in the morning energy dip group would experience beneficial effects of the light. Especially late types may have suffered from so called 'social jetlag' and may have accumulated sleep debt during previous working days (Wittman et al. 2006). Late types have also a higher chance to receive blue morning light on a sensitive part of their clock phase (Rüger et al. 2013). Therefore they had a higher chance to experience beneficial effects of light in the morning. In contrast to the present study, some studies indeed found positive effects of morning light on alertness and performance (Górnicka, 2008; Geerdink et al. 2012, Smolders et al. 2012, Geerdink et al. 2016). Besides the fact that these studies used other light sources and durations, an important difference with the present study is that in the present study alertness and performance were assessed relatively late in the day (after travelling to work) in the working environment of individual participants with normal working demands. In one of our previous studies (Geerdink et al. 2012, Geerdink et al. 2016) we examined the decline in sleepiness at home directly after awakening, in late types only, which means that participants had a higher chance for sleep inertia (a state of lowered arousal after awakening, Tassi & Muzet 2000). Light is a factor that can reduce and/or shorten sleep inertia effects (Tassi & Muzet 2000). Other differences between the previous studies and the present study are that in the previous studies sleepiness was assessed directly after 30 or 60 minutes of blue light exposure, that a higher intensity of light was used, and that the studies were conducted in the home environment of the participants (Geerdink et al. 2012, Geerdink et al. 2016). Another study that also examined the effects of blue light later in the morning, i.e. two hours after wakening (Gabel et al. 2013), found also no effects of the blue light. It may be that blue light in the morning is only effective when it hits the right phase of the clock, and/or when sleep inertia is still present. Following up on this reasoning, with morning light exposure less improvement in performance would be expected in early types, compared to intermediate and late types, as they have an earlier diurnal peak of alertness and performance (Kerkhof et al., 1980; Monk et al. 1989). The relatively late exposure to blue light in the present study for early types, may explain why the morning energy dip group did not improve, but not why there is a trend for deterioration in performance in this group. Although speculative, a possible explanation is overstimulation of brain areas involved in alertness regulation, as these areas are already active and may get too much input via the extra blue light in these early types. This is an interesting further study perspective by itself.

Extra blue light appears to have different effects at different times of the working day and the effects appear to be different for different chronotypes. This indicates that the mechanisms and regulation of alertness and cognitive performance is complex. Future research should also examine the effects of extra blue light during periods of low energy during the day over more days or for longer periods during one day. It would be interesting to explore if this could have more and/or different effects than one day of 3 hours of light exposure. In addition, there are indications that extra light during the day may even improve sleep quality at night (Aries 2005, Viola et al. 2008, Leger et al. 2011, Geerdink et al. 2016, Geerdink et al. submitted), which in turn may result in better performance and alertness during work.

Conclusion

Extra blue light in the work environment seems particularly beneficial for people that experience an energy dip in the afternoon, as light during this time stabilized cognitive performance. At noon the blue light is effective in improving performance for those people that suffer from a dip at this time, but after turning off the light a deterioration in performance can be seen, while there appears to be no effect on sleepiness. For those that suffer from reduced energy during the first morning hours at work or during noon, the extra light does not seem to be helpful and may even have a deteriorating effect, especially on the performance of early types.